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Engineering students' self-efficacy and goal orientations in relation to their engineering design ability

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ABSTRACT: Self-efficacy has been shown to be positively related to undergraduate engineering students' academic achievements, but due to the multifaceted nature of engineering students' design ability, an evidence of how students' self-efficacy and their goal orientation support design skills is still lacking. The purpose of this study was to examine the roles of self-efficacy and achievement goal orientation within the scope of task value on students' design ability. This research was carried out in the academic year 2017/2018 among 101 engineering students at Cracow University of Technology, Kraków, Poland. To examine students' beliefs and performance in engineering design, complex instrumentation was used, which consists of two surveys and a creative engineering design test. Findings revealed that self-efficacy is related to engineering design skills directly and indirectly, where performance (ego) goal orientation mediates achievements. Engineering self-efficacy predicted creative engineering design, while students' intrinsic value in engineering predicted their intentions to persist in the engineering task. The study showed that the developed model was capable of identifying individuals' self-concepts specific to the engineering design tasks.

Keywords: Engineering education, self-efficacy, goal orientation, expectancy-value theory, engineering design

INTRODUCTION

National economy competitiveness and prosperity are substantially linked to the production of scientists and engineers [1]. Thus, policy makers in some countries (e.g. China, South Korea, Germany) had already prepared reforms to increase the number of students receiving engineering degrees, by means of evidence-based changes to academic, government, and industrial programmes. Many other countries are still faced with the lack of engineering students, and how to retain those who are already enrolled, but want to drop out. Moreover, an engineering design study as a peak engineering activity still suffers from a lack of good designers, even more, the question of how to recruit students with higher engineering design abilities is a central focus of several development department and design laboratories [2-5].

Several studies have revealed that self-efficacy in engineering is important, because individuals with low self-efficacy have lower levels of achievement and persistence in engineering majors [4-6]. Moreover, Bandura has argued that self-efficacy dimensions, such as task selection, stability, focusing and ability affect behaviour [7]. Studies have also indicated that students' intramural activities, learning formations and reasons for the performance level of their academic tasks can be monitored by the achievement goal orientation theory [8]. Variables, such as motivation and self-efficacy have been associated with learning environment, and the authors have included studies of the effect of this relationship on academic achievement rather than on design skills [4-6][9].

Engineering design self-efficacy is highly dependent on engineering experiences [3]. According to Bandura's sources of self-efficacy, individuals can build their self-efficacy through engineering experience [7]. Opportunities for mastery experiences, vicarious experiences, social persuasion or positive and negative physiological states within engineering design may not naturally occur, unless the individual has had some sort of experience. The possibility does exist for negative experiences, but then those individuals are likely not to persist in engineering [3]. Finally, motivation, outcome expectancy and anxiety were shown to relate to self-efficacy toward engineering design. Though researchers have looked at students' perception of engineering and design [2-5]; little is known about the extent to which students relate various beliefs, goal orientation, creative-thinking and problem-solving skills to conducting engineering design.

SELF-EFFICACY AND GOAL ORIENTATIONS IN ENGINEERING DESIGN

Studies focused on undergraduate engineering students have shown that students' academic self-efficacy predicts both academic achievement and persistence [10]. When students believe in their own efficacy to achieve tasks, they become motivated to act in ways that make their success more likely [7]. Self-efficacy often works in concert with other motivational belief systems that influence students' academic behaviours and choices, such as mastery goal orientation, task value and interest [2]. Students who believe in their own capabilities also tend to engage in their work for their own mastery and find their work useful and interesting [11].

A large meta-analysis found that across many academic majors, self-efficacy was related to student performance and persistence with a stronger relationship between self-efficacy and academic performance for low achieving students. In the field of engineering, education self-efficacy among university students has also been found to be related to achievement and persistence, as well as motivation, outcome expectancy and anxiety [2]. For freshmen, self-efficacy in engineering is based on comparisons with others, performance on tasks, mastery of material, contributions while working with others and grades. Moreover, the types of engineering activities students engage in can have a differential impact on individuals leading to either decreased or increased self-efficacy [12]. For example, team-based service projects have been found to increase self-efficacy [12], but due to the engineering project-based experiences, not the project structure itself that has an impact on self-efficacy [2].

According to the expectancy-value theory [13], the two significant components of understanding students' achievement behaviours and academic results are how sure the students are of themselves in achieving an academic task (self-efficacy), and their beliefs about how noteworthy that task is (task value). The expectancy-value theory assumes that students' learning objectives are a factor of their self-efficacy and task value [13]. Researchers suggest that self-efficacy beliefs influence academic motivation and achievement, given that students with higher self-efficacy tend to participate more readily, work harder, pursue challenging goals, spend much effort toward fulfilling identified goals and persist longer in the face of difficulty [7][8]. Therefore, students not only need to have the ability and acquire the skills to perform academic tasks successfully, they also need to develop a strong belief that they are capable of completing tasks successfully [6]. An individual's self-efficacy relates to the underlying reasons for why success or failure resulted in a subsequent effort level. For instance, success due to luck rarely leads to a belief that warrants future similar actions. People who regard themselves as having high self-efficacy attribute their failures to insufficient effort. Those who regard themselves as having low self-efficacy attribute their failures to low ability [11].

Students' achievement goals are an integrative construct that addresses the purpose or the orientation that guides or explains student behaviour in an achievement situation by focusing on *why* students choose to engage in a particular activity or task, as well as on the criteria they establish to evaluate their competence in the task [8]. These two dispositions are generally referred to as *mastery (task, learning) goal orientation* and *performance (ego) goal orientation*. Mastery goal orientation is associated with students desiring to learn new material and skills because they want to improve, and success is defined relative to the student's improvement. Performance orientation is associated with students desiring to demonstrate their ability relative to their peers, and success is defined relative to other students [4]. Both mastery and performance goal orientations have been further divided into two components creating a two-by-two framework for goal orientations: mastery-approach, mastery-avoidance, performance-approach and performance-avoidance. Mastery-approach is characterised by students wanting to deeply learn course material, whereas mastery-avoidance is characterised by students wanting to avoid not learning. Performance-approach is characterised by the student wanting to outperform (normative) peers in knowledge, skills and abilities. Performance-avoidance is characterised by the student wanting to avoid looking incompetent or displaying poor abilities in front of peers [4].

Some have reported that mastery goals are positively associated with adaptive motivational outcomes such as choice, persistence, engagement, self-efficacy, deep study strategies [3][4][8][10], while some also reported that mastery goals are not consistently found to be predictive of academic outcomes [4]. Unlike mastery goals, performance-avoidance goal orientations can be associated with maladaptive processes (e.g. reduced help seeking, cheating, self-handicapping, anxiety) and lower grades. However, performance approach goals have been inconsistently linked to academic outcomes. Sometimes students with high-performance-approach goals demonstrate higher grades, while other students with high-performance-approach goals demonstrate lower grades. Appearance-framed performance-approach goals tended to be negatively related to academic outcomes, and normatively-framed performance-approach goals tended to be positively related to academic outcomes [4].

Engineering design is regarded as the peak of creative engineering activity; its results are often the absence of some effect rather than the presence of some observable feature. Engineering design is creativity, consumes resources (information, material, energy), has a purpose, and can therefore be assessed and evaluated. With engineering design, a reduction of uncertainty theory is applied following characteristics of engineering design [14]: 1) design problems are always subjected to certain conditions; 2) conditions are benchmarks for final decision making about the solution; 3) a design problem is very often a decision-making problem; 4) information management is crucial to reach a satisfactory solution; 5) a design problem is a real-world problem. The needs are met on the physical plane; 6) design problems do not have a single response; and 7) design theories have a high degree of abstraction and the best solution is an ideal design, which is achieved by systematically applying advance design theories. Moreover, at engineering design graduates require sophisticated problem finding and solving skills, critical thinking and quantitative reasoning skills [15], especially where they connect engineering with real-life situations [16]. Considering the aforementioned, the effectiveness of engineering education might increase in creativity, multiple learning, and visualisation ability development [14], especially in the increasingly complex world, where engineering students need to learn innovation and complex problem-solving in socio-technical contexts [17]. Innovation in functional design and embodiment design is less necessary, since industry requires mostly design improvement, with a focus on reducing costs and increasing the quality and variety of products, to meet changing market demands [18].

Previous findings suggest that cognitive processes play an important role in students' motivation to persist in the face of challenge or to put forth effort when academic tasks become difficult. The goal of this study was to link the three areas of research by examining the interaction between students' self-efficacy, goal orientation and design ability as student achievement. In this study, self-efficacy refers to one's belief that ability can grow with effort, belief in own ability to meet specific goals and/or expectations and belief to be proactive in engineering design tasks. The motivation was also to investigate how students' different sources of self-efficacy influence goal orientation and consequently, how goal orientation can be associated with engineering design ability (see Figure 1). Understanding the mechanism that extends from self-efficacy to design skills is also important for instructors/educators, who are one of the most important factors in the learning environment. When providing feedback to a student, an educator who is conscious of this mechanism will understand whether the main message is sent to self-efficacy or to goal orientation.

Based on the previous theoretical literature on self-efficacy, goal orientation and design thinking, the following research questions guided this study:

1. What is the level of self-efficacy of engineering students?
2. What is the level of engineering design ability of engineering students?
3. How well do students' scores on the self-efficacy and each of the goal orientations scales predict design ability?

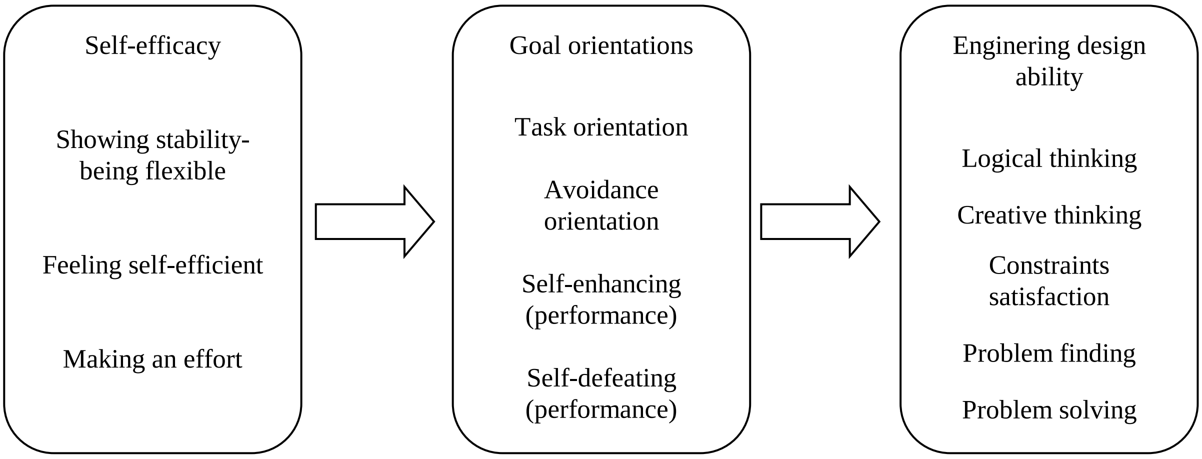

Figure 1: Conceptual model of the study.

METHOD

Sample

The sample of the study consisted of undergraduate students at Cracow University of Technology, Kraków, Poland. A total of 101 students volunteered to take an anonymous paper and pencil survey (67 male students and 34 female students). Students reported intending to major in a wide variety of engineering subfields. The distribution for the majors in engineering for the total sample was as follows: 68 (or 67.32%) mechanical; 13 (or 12.87%) chemical; 14 (or 13.86%) electrical; and 6 (or 5.94%) materials science students. These students consisted of both full-time (91) and part-time students (10) with average age of 22.44 years.

Instrumentation

Self-efficacy. Engineering self-efficacy items were developed and evaluated to reflect the multifaceted nature of self-efficacy in engineering. The authors' goal was to create self-efficacy items that represented beliefs about engineering at levels and that would pertain to students in most engineering disciplines. The developed instrument was based on a questionnaire by Gaumer Erickson et al [19], using a six-point Likert scale (0-strongly disagree to 5-strongly agree) comprised of 14 items, the sub-dimensions are: showing stability - being flexible (5 items), feeling itself efficient (4 items) and making an effort (5 items).

Achievement goal orientation. A survey was developed based on findings of Pipa et al [8], with 18 items measuring four goal orientation sub-scales: mastery goals (6 items), avoidance orientation (4 items), self-defeating performance orientation (4 items), and self-enhancing performance orientation (4 items). For each questionnaire item, students were asked to rate whether they *agree* or *disagree* with the statements using a 5-point Likert scale, with scores ranging from 1 (strongly disagree) to 5 (strongly agree).

Engineering design. To test engineering design ability, a modified test for creative design assessment was used [20]. The instrument consists of three design problems with five parts each to assess an individual's ability to formulate and express design ideas through sketching, providing descriptions, identifying materials, and identifying problems that the design solves and its potential users. Participants are to generate up to two designs per problem. Total time for this assessment is 30 minutes for three problems, or about 10 minutes per problem.

Procedure and Data Analysis

During a real-world class, students were invited to complete the two surveys and a test. A total allotted time for administering the survey was 45 minutes. The survey was conducted in September and October 2017 depending on the activity plan. A high response rate was obtained because of the direct presence of teachers or instructors and the way the survey was administered.

Data analysis was conducted using SPSS and AMOS software. Descriptive analyses were conducted to present the student basic information, and the mean score of dependent variables. An ANOVA and MANOVA analysis were conducted to find and confirm significant relationships between groups with an effect size calculated with eta squared. SEM was used as a modelling framework.

RESULTS

Reliability and Descriptive Statistics

The Cronbach's coefficient alpha values, based on the sample of this study, indicated that the instruments are highly reliable (Table 1), with all Cronbach's alpha values being > 0.80. Students' descriptive statistics are expressed with a mean (M) and standard deviation (SD).

Table 1: Reliability information Cronbach's alpha on instruments used in the study with students' descriptives.

Scale	Sub-scale	Cronbach's alpha	M	SD
Self-efficacy	Showing stability-being flexible	0.93	3.52	1.11
	Feeling itself efficient	0.95	3.07	1.22
	Making an effort	0.96	3.02	1.34
Goal orientations	Task orientation	0.81	4.05	0.72
	Avoidance orientation	0.87	1.46	0.71
	Self-enhancing	0.81	4.22	0.61
	Self-defeating	0.83	2.78	0.89
Engineering design	Fluency	0.90	23.27	10.48
	Flexibility	0.91	20.48	7.96
	Originality	0.88	19.05	5.51
	Usefulness	0.87	14.05	3.88
	Total	0.89	76.81	25.96

Engineering students perceived their self-efficacy as being above average considering a mid-point of 2.5. Surprisingly, a sub-scale of showing stability-being flexible is a dominant, while their perception about own ability and ability to grow with effort seemed not to be strong. Students still prefer mastery orientation and well-designed tasks to be accomplished. They also do not find engineering subjects and content to be tedious. Moreover, students like to compete or to out-do their peers in tasks in which awareness of the consequence of technologies is encountered. The engineering design ability test also revealed that students are able to think logically and critically, and are able to take into account all constraints in engineering design. Moreover, ability with problem finding seems to be more important than the ability to solve problems.

Modelling

Model fit tests were done in AMOS IBM software, and a path model of interrelated factors of self-efficacy, goal orientation and creative engineering design ability with significant ($p < 0.001$) standardised path coefficients (n = 101) as shown in Figure 2. Exogenous entries in model were self-efficacy sub-scales while endogenous variables were goal orientations and engineering design ability. All exogenous variables effects were hypothesised to be significantly correlated with both positive and negative outcomes. After the attenuation corrections, a final model was created (Figure 2). According to commonly used fit indices [21], the authors found that the fit of this model was very close. A nonsignificant *p*-value (0.45) was observed from the Chi-squared test (16.11), and the Chi square divided by its degrees of freedom was smaller than 5 (1.01). The goodness of fit index, the comparative fit index, and the Tucker-Lewis coefficient values were larger than 0.95 (0.96, 0.99, and 0.99, respectively), and the root mean-squared error of approximation and the root mean-squared residual were smaller than 0.05 (0.01 and 0.04, respectively). The probability of close fit was larger than 0.05 (0.69). The probability level of the test of close fit was also higher than the proposed threshold level of 0.50 for a good model fit [21]. This indicates a great initial model that does not need any improvement.

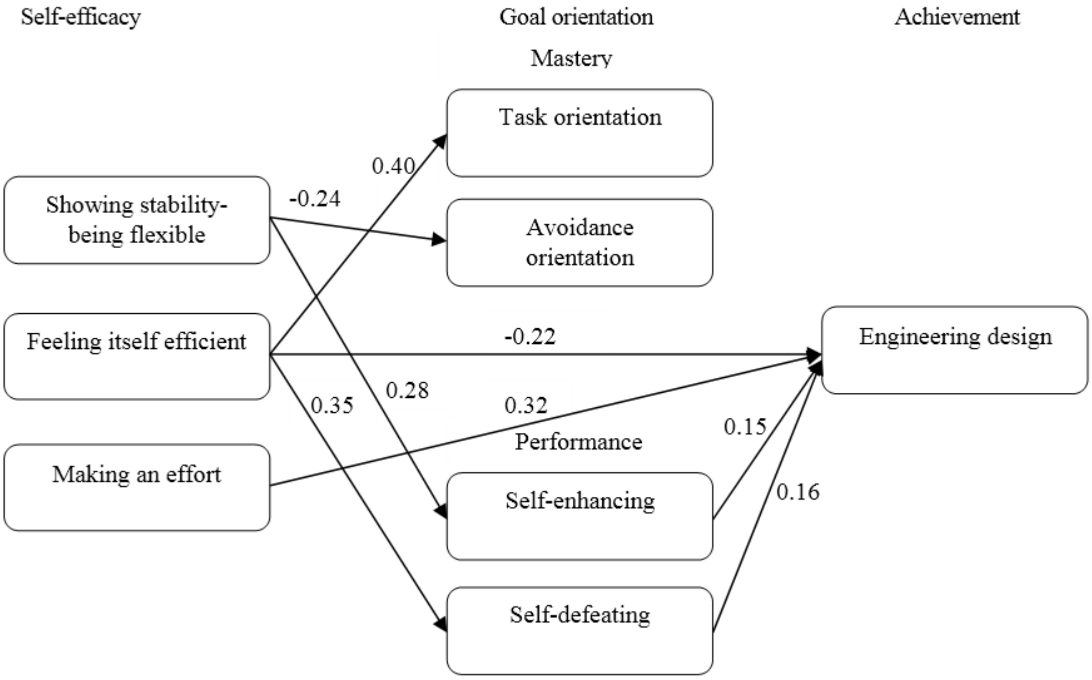

Figure 2: A model of interrelated factors of self-efficacy, goal orientation and creative engineering design ability with significant ($p < 0.001$) standardised path coefficients ($n = 101$).

The significant path coefficients varied from medium (0.15) to strong (0.40), and the authors considered the absolute rate. Self-efficacy was found to be an adequate predictor in both goal orientations and engineering design ability, with direct and indirect effects. Two path coefficients had negative estimates. The negative path coefficient for the self-efficient feeling to engineering design ability means that highly satisfied and as self-assessed very efficient students scored lower in the engineering design test. The second negative correlation was found on the path showing stability-being flexible, where the students are very proactive and do not like to avoid assigned tasks. Students who perceived themselves as being very efficient pose algorithmic behaviour and prefer mastery goal orientation while for performance avoidance orientations show insensitivity to failure. Students with ego-related goals, both those that like to outperform peers and those that like to avoid negative judgments from others, scored higher in the engineering design test.

DISCUSION AND CONCLUSIONS

The results reported in this study indicate that self-efficacy affects both students' goal orientation and their design skills. Self-efficacy might act with direct effects through belief that one's ability can grow with effort and that one is able to meet specific goals and/or expectations. Moreover, the authors confirmed the finding of Carberry et al that engineering design self-efficacy is highly dependent on engineering experiences especially at performance goal orientations [3]. Mastery goal orientation is significantly affected by belief in one's own ability, while there is no evidence that mastery goal orientation influences creative engineering design, perhaps due to the students' lack of experience. Opportunities for mastery experiences, vicarious experiences, social persuasion or positive and negative physiological states within engineering design may not naturally occur unless the individual has had some sort of experience [3].

In contrast, the best engineering students considering their grade point average also seem not to be the best designers. This finding is especially important for recruiting the best designers. Nevertheless, engineering subject matter and accompanying tasks should be designed in a way to enhance the proactivity of students, since a proactive engineering behaviour was found effective at both mastery and performance goal orientation. Also, the effect of engineering study on engineering design was mediated by performance goals, while mastery goals mediate academic outcomes, as is argued by Rambo-Hernandez [4].

Nevertheless, as argued by Pipa et al, goal orientations may vary according to the specific context or subject, suggesting the analysis for specific engineering fields as a path for future research [8]. Future studies should also explore an alternative organisation for performance (*ego*) orientations and address the developmental trajectories of goal orientation across gender and different experience levels.

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BIOGRAPHIES

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